

Evaluating the Performance of Common Emitters Types in the Central Region of Saudi Arabia

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Abstract. A field study has been carried out to evaluate the performance of seven common types of on-line emitters in the central region of Saudi Arabia. The emitters have been chosen to represent three major types of emitters: laminar flow, turbulent flow and pressure compensating emitters. The emitters have been tested under different operating pressures. A simplified procedure has been developed to perform a comparison between the theoretical and the measured emitter flow rates, considering the effect of head loss along the lateral. The tested laminar flow emitters have shown a noticeable difference between the measured and the corresponding nominal flow rates. Moreover, they have shown a non-uniformity of flow rates and unsatisfactory performance. Turbulent flow and pressure compensating emitters have shown a good uniformity of flow rates and their variations of flow rates due to manufacture were low. These emitters have also shown low difference between the nominal and measured flow rates. Therefore, they are recommended for use in the area under study.

Introduction

Trickle irrigation has a distinguished place among irrigation systems, especially in arid regions, due to its advantages in water saving where water resources are limited. In a trickle irrigation system, a small controlled amount of water is applied near the plant by the emitters. There are various types of emitters available commercially. Generally, emitters could be classified into three main types based on their modes of operation [1,35]: (a) laminar flow emitters, which are either microtubes or spiral long path emitting, (b) turbulent flow emitters, which are either tortuous long path emitter maintains turbulence with continuously changing flow direction, or the short path type which decreases the flow passage diameter under increasing pressure, and

(c) orifice emitters; which include the simple orifice, the vortex orifice and multiple orifices in series. Manufacturers have developed emitters that provide constant flow rate over a wide range of lateral line pressure known as the pressure compensating emitters.

Ideally, an emitter permits a uniform flow of water to trickle at constant flow rate that does not vary significantly throughout the field. From a practical point of view, it is difficult to achieve this ideal performance because along the lateral there is a pressure gradient due to friction losses and, as a result, the flow rate of the different emitters will vary. Moreover, the design, manufacture and material quality control of emitters greatly affect their performance to deliver constant discharges [2]. The hydraulic specifications of emitters include the operating pressures at their inlet and the corresponding nominal flow rates expressed at water temperature of 25°C. Every manufacturer drew especially the relation of pressure to flow rate at a best performance for his emitter [3]. However, in many cases, the emitters are not carefully manufactured and no care has been paid to the standard specifications. Accordingly, a difference between the actual and the theoretical pressure-flow relationship is expected, which in turn affects the accuracy of the trickle network design.

In arid region conditions, where atmospheric demand is very high, the knowledge of the uniformity of water distribution from emitters is important to insure efficient irrigation practice. The Kingdom of Saudi Arabia is considered as a good example of the arid regions. The central region is the most important agricultural area in the Kingdom, where irrigated lands by trickle irrigation is expected to expand in the near future. Therefore, such studies concerning trickle irrigation evaluation should take more attention.

The objectives of the present work are to evaluate the performance of the common types of on-line emitters in the central region of Saudi Arabia, and to recognize the reliability of their nominal flow under different operating pressures.

Notations

The following symbols are used in this study:

- | | |
|----------|--------------------------------------|
| a | = cross-section area of the lateral. |
| C | = constant |
| C_{HW} | = coefficient of Hazen Williams. |
| d | = diameter of the lateral |

EU	= emission uniformity
EU _a	= absolute emission uniformity.
F	= coefficient.
i	= subscript identifying individual emitter.
K	= constant.
L	= distance between last emitter in the lateral and the lateral inlet.
n	= number of emitters along the lateral.
P	= operating pressure.
P _{av}	= average operating pressure along the lateral.
Q	= total flow at the lateral inlet.
q [*]	= average measured mean flow for number of emitters.
q _i	= emitter flow rate.
q _n	= average of the lowest 1/4 of emitters flows.
q _{nom}	= emitter nominal flow.
q _{nom} [*]	= average nominal flow for a group of emitters along the lateral.
q _x	= average of the highest 1/8 of emitters flows.
S _q	= standard deviation of emitters flows.
U _s	= statistical uniformity of emitters flow rates.
V _{qs}	= manufacturer's coefficient of variation.
x	= emitter flow exponent.
X	= distance between emitter and the lateral inlet.

Materials and Methods

A comprehensive survey of common emitters in the area was made. As a result, seven commercial marks of on-line emitters are collected from retail outlets. They are grouped into three categories according to their nominal flow rates. Adjustable emitters were excluded from this study. Illustrated in Table 1 are some characteristics of the seven emitters taken from their catalogues. The flow-pressure relationships of these emitters are collected from catalogs and redrawn in one graph as shown in Fig. 1.

Experimental work

The field work was conducted at the Agricultural Research Station, Al-Qassim Branch of King Saud University, Buriadah (Latitude 26° N, Altitude 44° E and

Table 1. Some characteristics of the chosen emitters

Group	Commercial name	Emitter type	Features	Specifications
A (8 l/h)	E-2*	(I) Laminar flow	<ul style="list-style-type: none"> • Spiral flow path • Barbed outlet for remote water discharge • Removable key insert 	• 4 mm barbed inlet and outlet
	Turbo-Key*	((II) Turbulent flow	• Removable cap for cleaning	• Stable polypropylene and polyethylene material
B (4 l/h)	E-2*	(III) Laminar flow	as in No. I	as in No. I
	Key Clip*	(IV) Laminar flow	<ul style="list-style-type: none"> • Proven spiral flow path and removable key insert 	<ul style="list-style-type: none"> • Stable polypropylene material • 4 mm barbed inlet
	K-4*	(V) Turbulent flow	<ul style="list-style-type: none"> • Labyrinth turbulent water flow path • Barbed outlet for remote water discharge • Removable key insert 	<ul style="list-style-type: none"> • Stable polypropylene construction • 4 mm barbed inlet • 3 mm barbed outlet
	Turbo-key*	(VI) Turbulent flow	as in No. II	as in No. II
C (1.89 l/h)	Rain Bug**	(VII) Pressure compensating	<ul style="list-style-type: none"> • Highly insert silicone elastomer diaphragm • Self-piercing barbed inlet 	• Single outlet

* RIS, "Hardie Irrigation", Roma, Italy, 1989 [4].

** Rain Bird, "Turf Irrigation Equipment", Glendora, USA, 1992 [5].

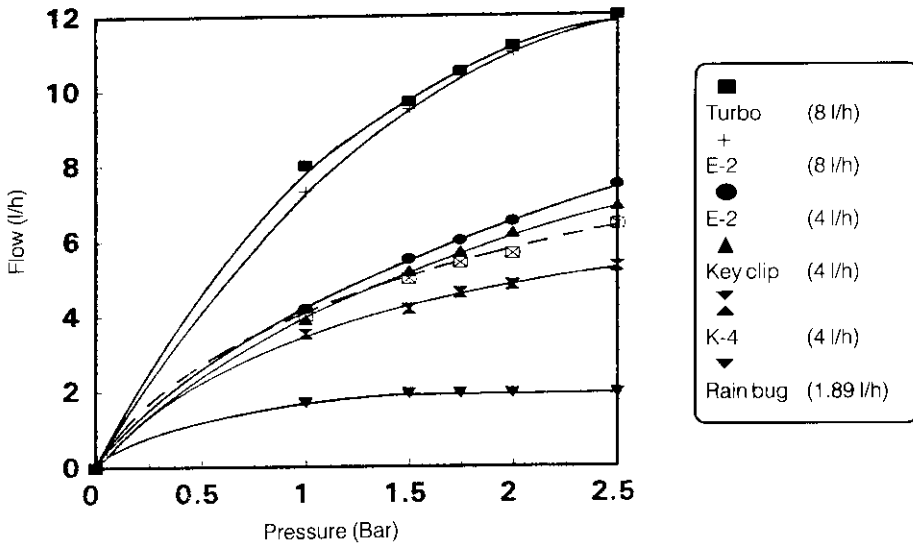


Fig. 1. Manufacturer's performance curves of emitters under evaluation .

elevation 625 m). It was carried out in October to December, 1993 when the atmospheric temperature was nearly 22 to 23°C. Irrigation water salinity in the site was about 1200 ppm.

A new trickle irrigation network was installed in a leveled area with no slope. Only one inlet along the manifold was chosen to carry out the study. For each type of emitter, a new polyethylene lateral was connected to the manifold. The lateral has an inner diameter of 13 mm with a total length of 100 m. A new calibrated pressure gauge was installed at the lateral inlet. The first emitter was fitted at a distance of 2 m and the subsequent emitters were fitted at 4 m spacing making the total number of emitters 24. A small hole was dug underneath each position of emitter and a catch can with a capacity of one liter was put in to receive the trickled water. The study was carried out under three operating pressures equal to 1.0, 2.0 and 2.5 bar (100, 200 and 250 KPa, respectively) at the lateral inlet and the pressure was controlled by a valve fitted after the pressure gauge. Before starting the test, water was left to flow for sometime from the lateral outlet to make sure that it flows freely from air bubbles and, then, the lateral outlet was closed. Applying the operating pressure P at the lateral inlet, the flow of each emitter was then measured using a graduate cylinder and a digital stop watch. This procedure was carried out for the seven emitters types.

Evaluation's Criteria

The following are criteria by which the different emitters types will be evaluated in this study:

1. Emitter flow variation

which is a measure of the variation of the emitter discharge rate.

- (a) The manufacturer's coefficient of emitter variation: it reflects the normal distribution of emitter discharge variation. The emitter flow variation is determined as follows [6]:

$$V_{qs} = \frac{S_{qs}}{q^*} \quad (1)$$

$$S_q = \left\{ \frac{1}{n-1} \left[\sum_{i=1}^n q_i^2 - \frac{1}{n} \left(\sum_{i=1}^n q_i \right)^2 \right] \right\}^{\frac{1}{2}} \quad (2)$$

$$q^* = \frac{1}{n} \sum_{i=1}^n q_i \quad (3)$$

where:

V_{qs} = the manufacturer's coefficient of variation.

q^* = mean flow for a number of n emitters tested at a fixed pressure and temperature.

S_q = standard deviation of emitters flows.

i = subscript identifying individual emitter.

Typical values of V_{qs} may range from 0.02 to 0.1 for non-compensating emitters and even to above 0.1 for some pressure compensating emitters, depending on the type of emitter and the consistency of the pressure by which the emitter is made [2].

- (b) Statistical uniformity: emitter flow variation can also be evaluated by determining the statistical uniformity as follows:

$$U_s = 100 (1 - V_{qs}) \quad (4)$$

where U_s is the statistical uniformity of the emitters flow rates.

The general criteria for an acceptable statistical uniformity is 90% or more, excellent; 80 to 90%, very good; 70 to 80%, fair; 60 to 70%, poor; and less than 60%, unacceptable [6].

2. Emission uniformity

Two parameters are applied herein to express as suggested by [7, pp.50]. They are:

- (a) **The emission uniformity (EU):** which can be considered as the most important factor of application uniformity and is defined as the ratio of the minimum to the average of emitter flow rates as a percentage:

$$EU = 100 \left(\frac{q_n}{q_s} \right) \quad (5)$$

where q_n is the average of the lowest 1/4 of emitter flow rates. According to [6], EU% is considered as excellent; good; fair; poor or unacceptable when its value is 100-94; 87-81; 75-68; 62-56 or less than 50%, respectively.

- (b) **The absolute emission uniformity (EU_a):** which is the parameter of application uniformity, including the maximum and minimum flow rates, and can be calculated as follows:

$$EU_a = 100 \times \frac{1}{2} \left(\frac{q_n}{q_s} + \frac{q_x}{q_x} \right) \quad (6)$$

where q_x is the average of the highest 1/8 of the emitter flow rates.

3. Characterizing the flow regime of emitters

The flow rate of an emitter may be characterized by the following equation [8, 31]:

$$q = KP^* \quad (7)$$

where:

- q = emitter flow rate.
 P = operating pressure.

- K = a constant of proportionality that characterizes each emitter.
- x = the emitter flow exponent that is characterized by the flow regime as follows [2] and [6,40]:
- a laminar flow regime corresponds to $x = 1$.
 - a fully turbulent regime corresponds to $x = 0.5$.
 - an intermediate stage corresponds to $0.5 < x < 1$.

The lower the value of x , the less the flow is affected by pressure variation. For long path flow emitter, $0.5 < x \leq 1.0$. For fixed orifice and nozzle type emitters $x = 0.5$. For pressure compensating emitters, $0.0 \leq x < 0.5$. Having known the emitter flow rate at two different operating pressure heads, the exponent (x) can be determined by measuring the slope of a log-log plot of P vs. q , or analytically by:

$$x = \frac{\log(q_1/q_2)}{\log(p_1/p_2)} \quad (8)$$

where q_1 and q_2 are emitter flows at two different operating pressures p_1 and p_2 respectively.

Results and Analysis

1. Emitter flow-distance

The location of emitter is identified by the relative position X/L , where X is the distance between the emitter and the lateral inlet and L is the distance between the last emitter and the lateral inlet. Under the three operating pressures P , the relationships between the measured emitters flow q and the corresponding values of X/L are shown in Figs. 2, 3 and 4 for emitters of groups A, B and C, respectively. For emitters of group A with a nominal flow of 8 l/h (Fig. 2), non-uniformity of flow of emitter type I (laminar flow type) can be seen along the lateral. On the other hand, a much better uniformity of flow is noticed for emitter type II (turbulent flow-type). However, there is a sharp drop of flow noticed at the lateral end for this emitter type which may be attributed to their imprecise manufacturers. For emitters with a nominal flow of 4 l/h (Fig. 3), one can see the non-uniformity of emitters types III and IV (laminar flow type) along the lateral. In addition, there are some extreme values of q noticed in case of emitter type III. Therefore, these values will be excluded during the evaluation procedure. Referring to Fig. 3, one can notice the very good uniformity of emitters types V and VI (turbulent flow type) except one extreme value of q in case of emitter type V which will also be excluded during the evaluation procedure. Figure

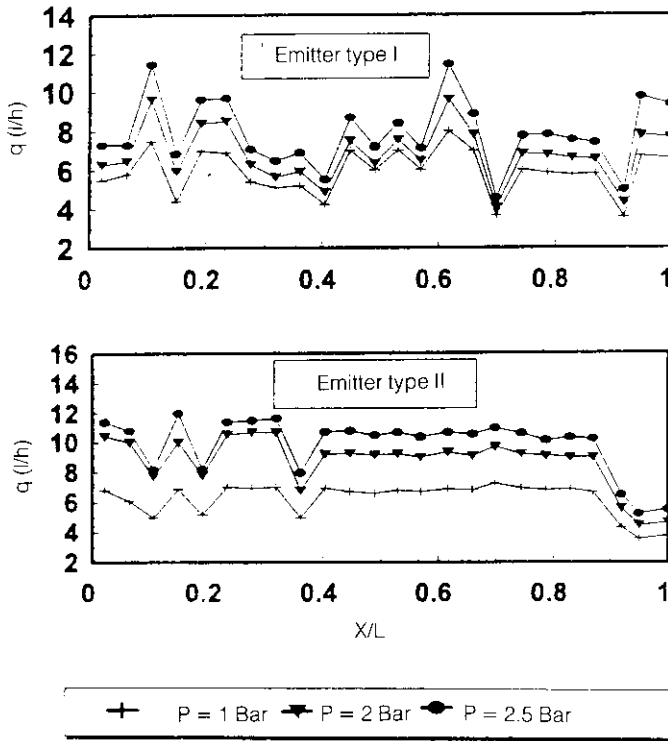


Fig. 2. Distribution of emitter flow rates along the lateral of group A .

4 shows the flow distribution of emitter type VII (pressure compensating type). Although this emitter type has the advantage of giving a nearly constant flow rate under a wide range of pressure as shown from its performance curve (Fig. 1), the field measurements show a noticeable difference between emitter flow rates under the applied operating pressures and doubling the operating pressure from 1 to 2 bar caused an increase of emitter flow q by about 36%. However, this type of emitters shows a good uniformity of flow along the lateral.

2. Measured and nominal emitters flow rates

A comparison between the theoretical and the measured emitter flow rates is valuable to investigate the emitter performance efficiency. However, comparing the average measured emitters flows q and the emitter nominal flow q_{nom} , at a specific value of P is not logical. This is due to the head loss along the lateral Δh , where the emitter operating pressure decreases as the emitter distance from the lateral inlet X

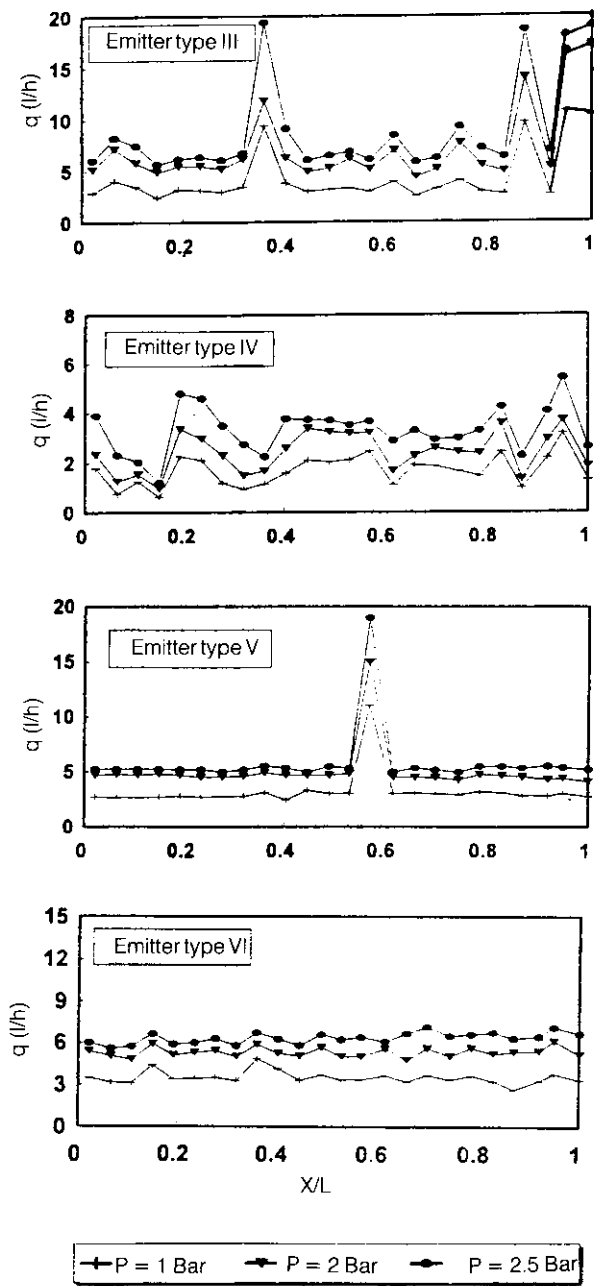


Fig. 3. Distribution of emitter flow rates along the lateral of group A.

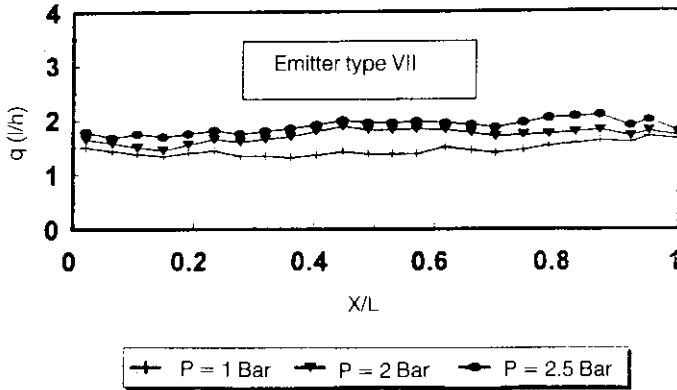


Fig. 4. Distribution of emitter flow rates along the lateral of group A.

increases. Accordingly, the average nominal flow rate for a group of emitters along the lateral q_{nom}^* should be less than the nominal flow rate of an emitter q_{nom} . Thus, the determination of q_{nom}^* is essential to perform such a comparison between the theoretical and the measured average flows for a group of emitters. The following procedure is developed to determine q_{nom}^* considering the head loss along the lateral:

1- calculate flow velocity v through the lateral assuming that all water is carried to the end of the lateral:

$$v = \frac{q_{nom} \cdot n}{a} \quad (9)$$

where:

- q_{nom} = nominal flow of emitter at a specified value of P (Fig. 1).
- n = number of emitters along the lateral.
- a = cross-section area of the lateral.

2- using the Hazen-Williams equation to determine the head loss along the lateral Δh [8,46]:

$$\Delta h = FCL (Q/C_{HW})^{1.852}/d^{4.865} \quad (10)$$

where:

- F = coefficient to compensate for the flow rate along the lateral and depends

on number of openings.

$C = 10.77$ for $h, L, d(m), Q (m^3/s)$.

$Q =$ total flow at lateral inlet.

$C_{HW} =$ coefficient of Hazen-Williams and equal to 150 for plastic or PVC pipes.

$d =$ diameter of lateral.

3- since the average operating pressure along the lateral P_{av} occur at 0.39 L at which 77% of Δh is resulted [7,71], then

$$P_{av} = P - 0.77 \Delta h \quad (11)$$

in which P is the operating pressure at the lateral inlet. Using Fig. 1, the average nominal flow for a group of emitters q_{nom}^* corresponding to P_{av} can be determined.

Figures 5, 6 and 7 show the comparisons between the average measured emitters flow rates q^* and the corresponding average nominal emitters flow rate q_{nom}^* for emitter of groups A, B and C, respectively, and for different values of P . Generally speaking, it can be noticed that q is always less than q_{nom}^* for all types of emitters. However, this difference varies according to emitter type and the operating pressure. For emitters of group A (Fig. 5), it can be seen that emitter type I (laminar flow type) has a high difference between q^* and q_{nom}^* and it reaches about 24% at $P=1$ bar and drops to 20.5% at $P=2.5$ bar. For emitter type II (turbulent flow type), less difference is noticed and it ranges from 13% to 10.5% at $P = 1$ and 2.5 bar, respectively. For emitters of group B (Fig. 6), emitter type III (laminar flow type) has the highest difference between q^* and q_{nom}^* and it is about 56% at $P=1$ bar. Emitter type IV (laminar flow type) has also a noticeable difference, but it is relatively less than emitter III and it is about 13.6% at $P=1$ bar. This may be attributed to its large water passage way compared to emitter type III and it may also be attributed to the emitter manufacturing.

Emitters types V and VI (turbulent flow type) have the minimum differences between q^* and q_{nom}^* and this difference nearly vanish at $P=2.5$ bar. For emitters of group C (Fig. 7), a small difference between q^* and q_{nom}^* is noticed. A general look at Figs. 5, 6, and 7 shows that the difference between q^* and q_{nom}^* decreases as the operational pressure P increases. This is attributed to the capability of high pressure to push out any accumulated salts in the water passage way compared to low pressure. One can conclude from the above analysis that there is always a noticeable difference between the theoretical (nominal) and the measured emitters flow rates in the laminar flow type compared to turbulent flow or pressure compensating types.

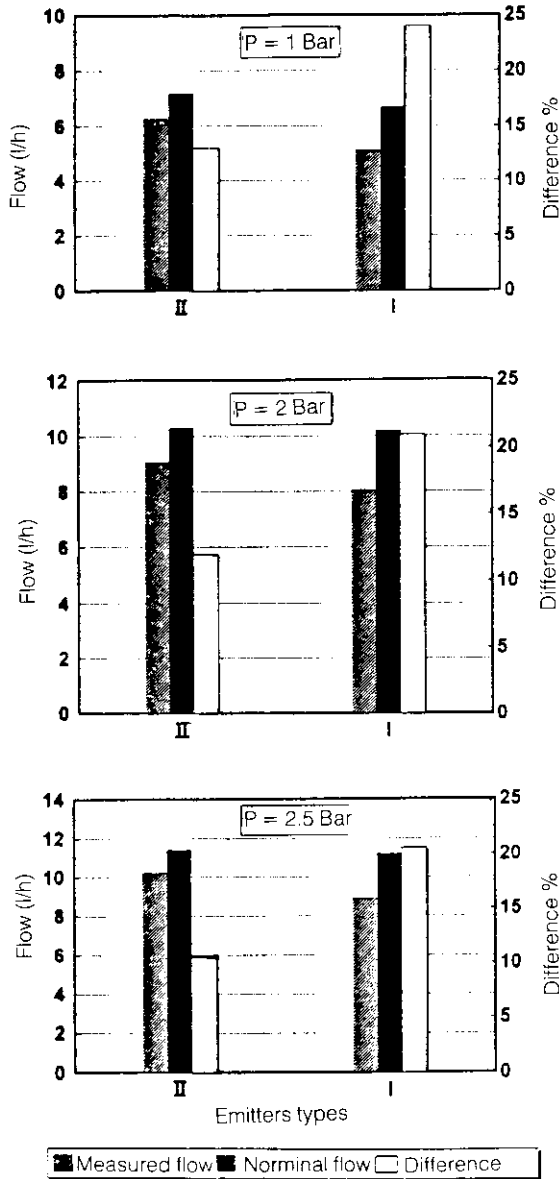


Fig. 5. A comparison between measured and nominal flows of group A.

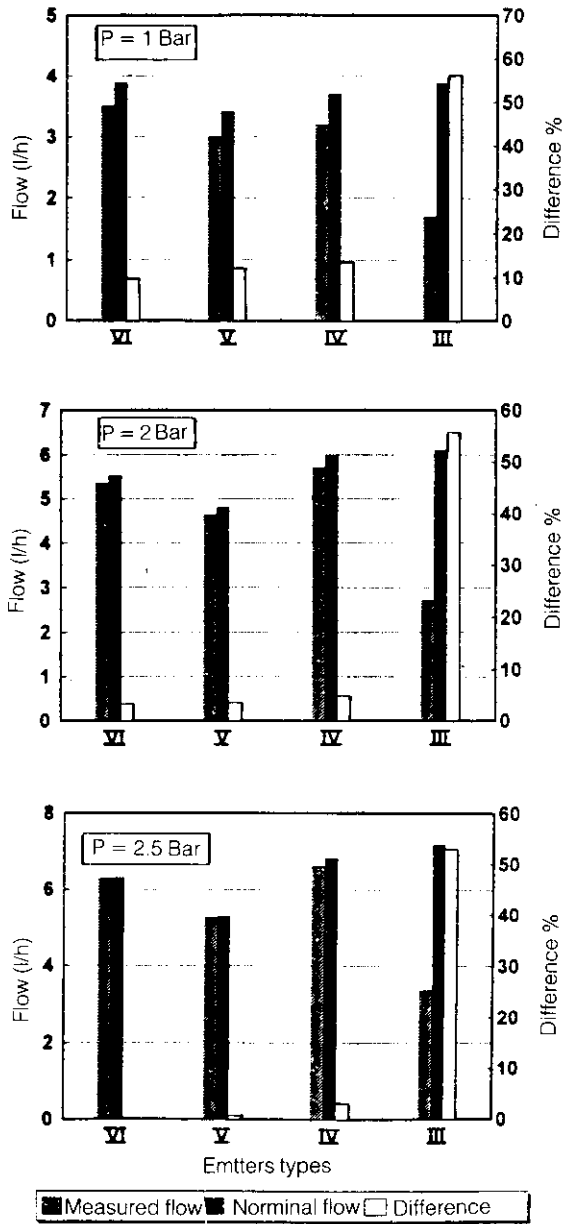


Fig. 6. A comparison between measured and nominal flows of group B.

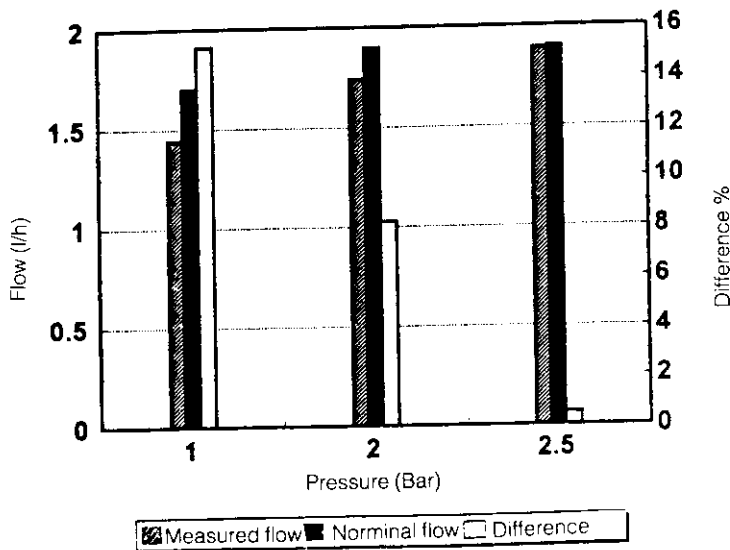


Fig. 7. A comparison between measured and nominal flows of group C.

3. Emitters evaluation

Applying Equations 1–8, different criteria for emitters' evaluation have been calculated and they are summarized in Table 2. The following remarks could be noticed from these results.

a) The non-pressure compensating emitters (NPC), with spiral flow path (Types I, II, IV), have given unsatisfactory performance with a manufacturer's coefficient of variation V_{qs} as high as 0.38 (emitter type IV) or more, while the reasonable value may range from 0.02 to 0.10 [2].

b) Fair or poor statistical uniformity of flow U_s and emission uniformity EU have been obtained for emitter type IV (laminar type). This is mainly attributed to its tiny water passage and, therefore, they can easily be blocked by any little particle in the water. However, emitter type III has very good values of U_s , EU and EU_a . This is attributed to its relative large flow path cross-section and, therefore, an increase of the flow rate is obtained compared to the other laminar flow emitter. This was clearly indicated in the comparison between the average emitter flow and the corresponding nominal flow rate (Fig. 6).

Table 2. Evaluation of different chosen emitters

Group	Type of emitter	P (bar)	Sq	Vqs	Us%	EU%	EUa%	x
A (8 l/h)	(I)*	1.0	1.174	0.2324	76.75F	73.116F	75.824	0.67
		2.0	1.614	0.20	79.95F	78.61 F	76.22	
		2.5	1.757	0.202	79.80F	75.127F	87.56	
	(II)*	1.0	1.104	0.17	82.9	81.03 G	85.3	0.502
		2.0	1.645	0.181	V.G. 81.18	79.20 G	80.26	
		2.5	2.257	0.22	V.G. 78.0 F	76.37 F	81.9	
B (4 l/h)	(III)*	2.0	0.909	0.159	84.08	84.41 G	80.68	0.70
		2.5	1.103	0.167	V.G. 83.29	87.02 G	82.15	
		1.0	0.647	0.3817	61.83P	60.59 P	61.64	
	(IV)*	2.0	0.8162	0.302	69.77P	58.63 P	79.31	0.61
		2.5	1.051	0.312	68.77P	65.13 P	64.27	
		1.0	0.214	0.073	92.69E	91.59 E	90.8	
C (1.89 l/h)	(V)*	2.0	0.1886	0.0704	95.93E	94.78 E	97.39	0.13
		2.5	0.189	0.036	96.43E	80.97 G	88.05	
		1.0	0.477	0.1365	86.35	89.77 E	83.72	
	(VI)*	2.0	0.3559	0.0666	V.G. 93.34E	92.85 E	90.91	0.55
		2.5	0.465	0.074	92.59E	90.55 E	90.12	
		1.0	0.148	0.1018	89.98	89.07 E	87.52	
(VII)**	2.0	0.207	0.1187	V.G. 88.13	91.10 E	84.70	0.13	
	2.5	0.32	0.169	V.G. 83.07	86.06 G	80.79		
	2.5	0.32	0.169	V.G.				

E: Excellent, V.G.: Very Good, G: Good, F: Fair, P: Poor

* Non-pressure compensating emitters (NPS)

** Pressure compensating emitter

c) Turbulent flow emitters have given a satisfactory performance of V_{qs} (emitters' type V and VI). They have excellent or very good values of U_s , EU and EU_a . This is attributed to their ability to cause turbulence to any silting in the water passage.

d) Pressure compensating emitter (type VII) has a quite higher value of V_{qs} than 0.10. This may be attributed to the difficulty to obtain manufacturing precision of materials used in this type of emitter. However, this type of emitter has very good to excellent values of U_s , EU and EU_a .

e) The emitter flow exponent x , for laminar flow emitters (Types I, III and IV), varies between 0.67 and 0.70 although it would be expected to have a value of 1.0. For turbulent flow emitters (Types II, V and VI), x ranges from 0.50 to 0.60 which agrees well with the expected value ($x = 0.50$). For pressure compensating emitters, x has a value of 0.13 which lies within the expected range for this type of emitter ($0.0 < x \leq 0.50$).

Conclusions

Concluding remarks from the field evaluation of the performance of locally available on-line emitters are as follows:

1) For laminar flow emitters, a noticeable difference between the measured emitter flow rate and the corresponding nominal flow rate is generally observed. A non-uniformity of flow rate along the lateral and an unsatisfactory performance are noticed. These types of emitters are characterized by their high values of the coefficient of manufacturer's variation.

2) Laminar flow emitters are not desirable if the used water has a high salinity because of their sensitivity to clogging by accumulating small particles in their narrow flow passage ways.

3) Turbulent flow and pressure compensating emitters are recommended to be used in the area under study, where very good uniformity of flow rate along the lateral is noticed and a negligible difference between the measured and nominal flows is obtained. Moreover, they are characterized by their low coefficient of manufacturer's variation.

4) Before selecting emitters for a new trickle system, it is recommended to do a field evaluation of different available types of emitters to select the most appropriate and efficient one.

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تقويم أداء أنواع المنقطات الشائعة في المنطقة الوسطى بالمملكة العربية السعودية

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(قُدّم للنشر في ١٤/٩/١٤١٤هـ؛ وقبل للنشر في ١٨/١/١٤١٥هـ)

ملخص البحث. تم إجراء دراسة حقلية بغرض تقويم أداء سبعة أنواع من المنقطات الشائعة في المنطقة الوسطى بالمملكة العربية السعودية تمثل ثلاث مجموعات رئيسية للمنقطات وهي: منقطات ذات التصرف المضطرب، منقطات ذات التصرف الطبقي ومنقطات استعاضة الضغط، كما تمثل أيضًا قيمًا مختلفة للتصرفات. وقد تم اختبار تلك المنقطات تحت عدة ضواغط تشغيل مختلفة. وقد تم استنباط طريقة مبسطة لإجراء مقارنة بين كل من التصرفات النظرية (الاسمية) والأخرى المقاسة مع الأخذ بالاعتبار تأثير الفاقد في الضغط على خط المنقطات. وقد أظهرت النتائج أن المنقطات ذات التصرف الطبقي تعطي فروقات كبيرة بين كل من التصرفات الاسمية والمقاسة، كما أظهرت أيضًا تلك المنقطات عدم انتظام تصرفاتها على طول خط المنقطات. أما المنقطات ذات التصرف المضطرب ومنقطات استعاضة الضغط فقد أظهرت انتظامًا جيدًا للتصرف مع وجود فروقات صغيرة بين التصرفات الاسمية والمقاسة، ولذا يوصي باستعمالها في منطقة الدراسة.

